Semi-Annual Progress Report

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3. Subject of Investigation:

"Relative Roles of Gravitational and Inertial Work in the Energy Cost and Character of Human Locomotion."

4. Period of Investigation:

July 1, 1964, through June 30, 1967.

5. Progress Report:

Research during the period July 1, 1966 - January 1, 1967, may be subdivided into two main categories:

(a) Continuation of the detailed analysis of human locomotion on the treadmill, as briefly reported in paragraph C of our semi-annual report dated July 3, 1966

(b) Effects of loading the trunk of a human subject on the energy cost, character, and efficiency of locomotion, as revealed by such analysis

Figure 1 shows an analysis of the energy level of each segment of the body (HAT, thigh, shank, foot) of a 19-year-old normal female subject, weighing 58.6 kg, lightly clothed in blouse, shorts, and rubber-soled shoes. The proportions by weight of the various parts of her body, as determined from volumetric displacement of each segment, and from specific gravities provided in the literature, were as follows: HAT (head + arms + trunk), 64.38%; thigh, 10.95%; shank, 5.40%; foot, 1.50%.

The energy expenditure of the subject in the experiment of Figure 1, determined from stabilized oxygen consumption, was 60.16 cal/1.22 sec, the duration of a cycle (from left heel strike to left heel strike) being 1.22 sec. The top curve of Figure 1, labeled "Body Total," shows the instantaneous mechanical energy levels of the body as a whole during one walking cycle. The lower curves of Figure 1 are corresponding curves showing total energies, kinetic energies, or potential energies, for each segment as labeled.

Figure 2 shows a similar set of curves for the same subject walking at the same speed but wearing a vest weighing 10 kg. This represents an increase of 17.1% of the body weight, and an increase of 27.9% of the weight of the HAT. It represents a load which is about at the limit of tolerance of the subject at the walking speed of 73.2 meters/min, cadence 100 steps/min.

In spite of this considerable increase in load, the step rate and therefore the step length were not altered. The energy expenditure was now 63.05 cal/1.22 sec, compared with the 60.16 cal/1.22 sec of the control experiment. This difference of 2.89 cal/1.22 sec, or 4.8%, obviously must reflect the increase in mechanical work which was done in the second experiment.

Comparison of Figure 1 and Figure 2 reveals the following:

1. The "Body Total" mechanical energy curve shows that the work output in experiment no. 2 is 0.93 cal greater than in experiment no. 1, representing an increase of 7.1%.

2. The "HAT Total" and "Both Legs Total" work outputs are approximately equal in the two experiments. The "HAT Vertical Kinetic" energy curve in the second experiment shows a work output significantly greater than that in the control experiment when expressed in percentage terms, but the absolute values in both experiments are so small that they do not enter significantly into the energy considerations with which we are concerned in the present discussion.

3. The "HAT Horizontal Kinetic" energy levels are relatively large in terms of the total, but, as in the preceding case, the absolute differences are so small that they do not enter significantly into the energy considerations under discussion.

4. The most striking difference between the curves of Figures 1 and 2 is the large absolute difference, 4.2 cal, as well as large percentage difference, 75%, in the "HAT Potential" energy changes. These large differences are due to a combination of an increase in the load being lifted and an increase in the height through which the load is being lifted.

It is clear from the preceding observations that the principal factor in the change in energy cost of walking when there is a substantial increase in the mass of the trunk is the gravitational work which is performed. However, even under conditions of earth gravity the effects of loading the trunk to a limit approaching the subject's tolerance have a relatively small effect upon the overall mechanical work performed and consequently upon the energy cost of doing the work. It may be anticipated that loading of the trunk under conditions of a weak gravitational field will have a very small effect upon the energy cost of normal locomotion, if it is assumed that other conditions remain substantially the same.

During the coming months the relative effects of trunk and limb loading will be analyzed by similar methods.

Respectfully submitted,

H. J. Ralston

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Figure 1

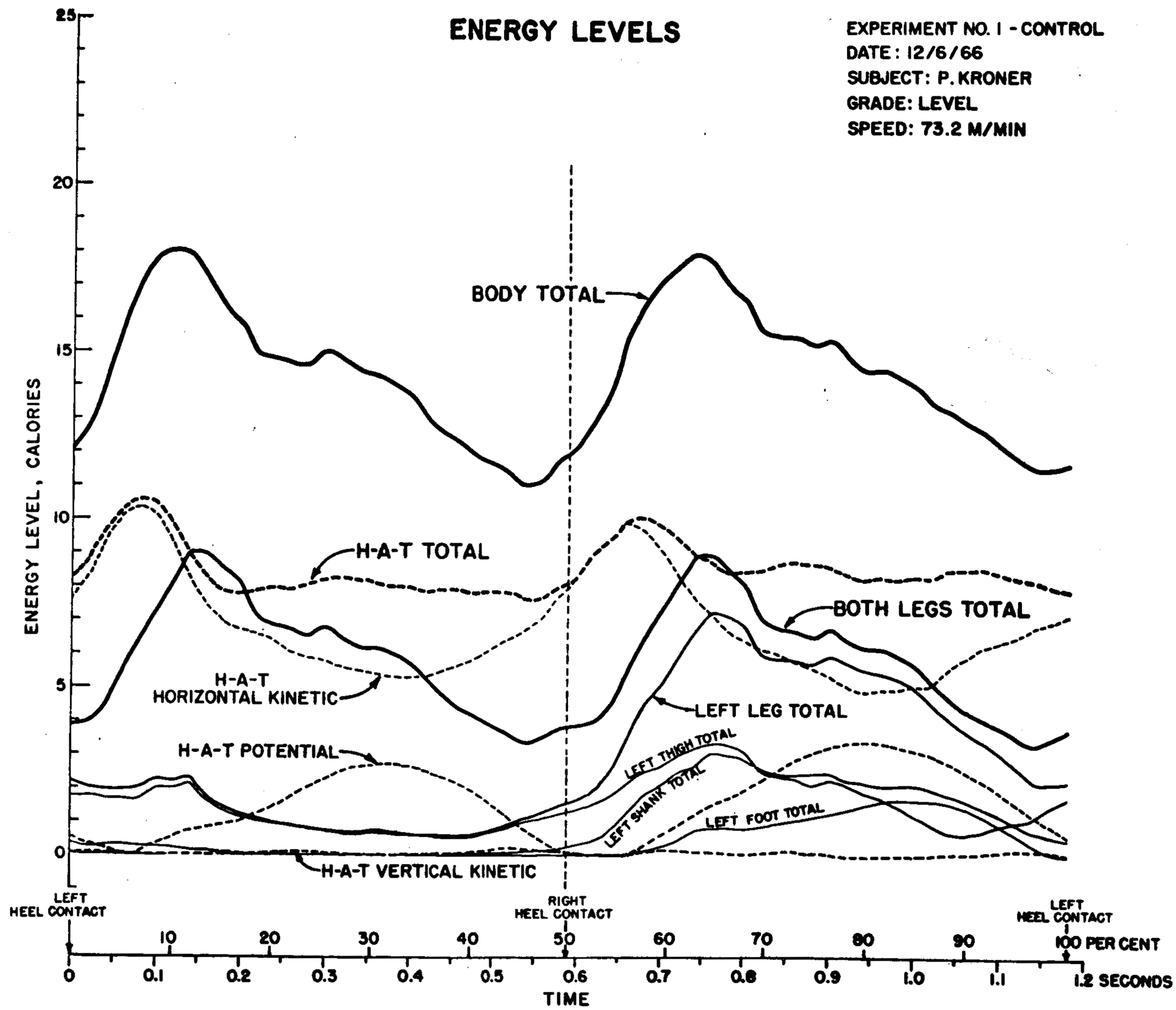
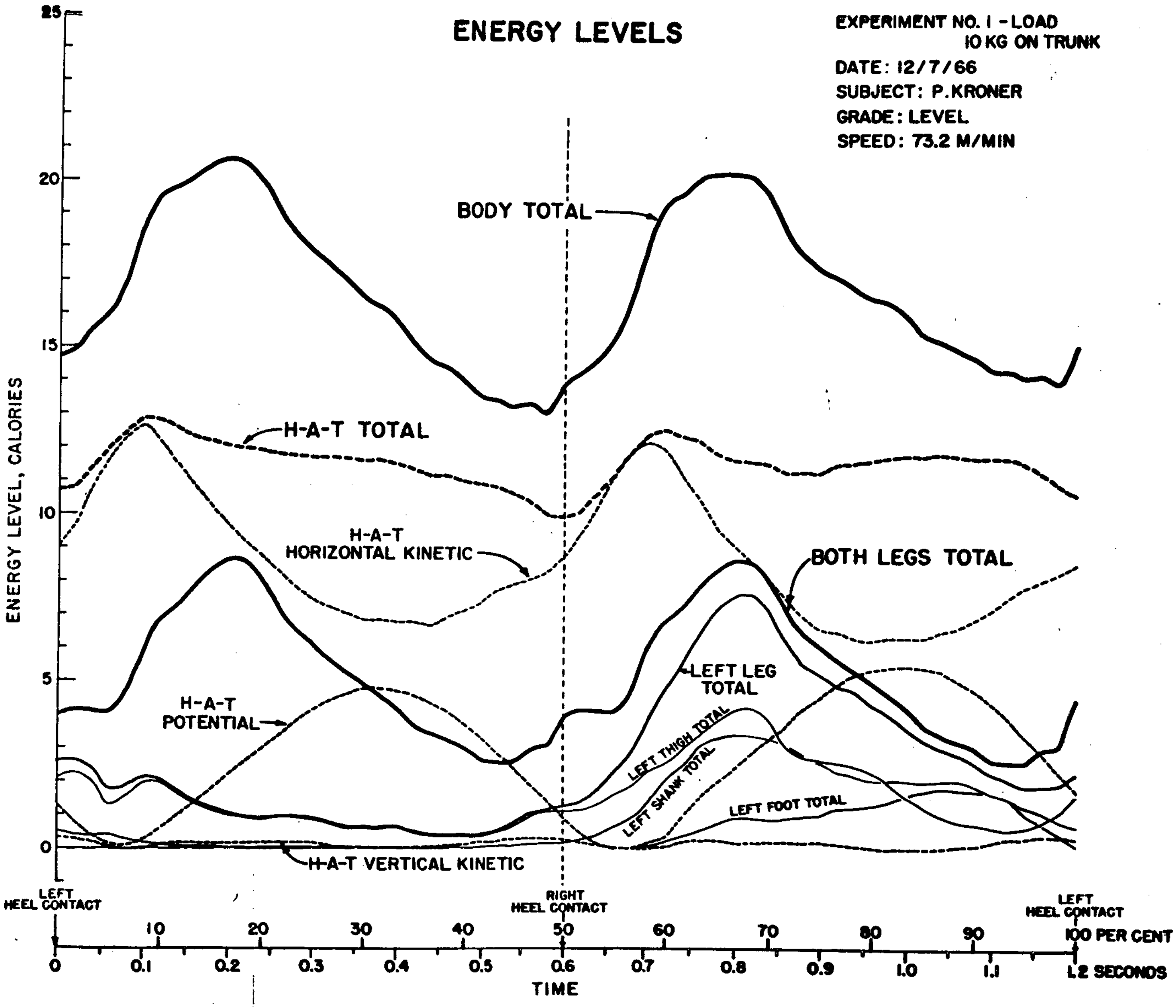

ENERGY LEVELS
EXPERIMENT NO. I - CONTROL
DATE: 12/6/66
SUBJECT: P. KRONER
GRADE: LEVEL
SPEED: 73.2 M/MIN
ENERGY LEVEL, CALORIES
BODY TOTAL
H-A-T TOTAL
BOTH LEGS TOTAL
H-A-T
HORIZONTAL KINETIC
LEFT LEG TOTAL
H-A-T POTENTIAL
LEFT THIGH TOTAL
LEFT SHANK TOTAL
LEFT FOOT TOTAL
H-A-T VERTICAL KINETIC
LEFT
HEEL CONTACT
RIGHT
HEEL CONTACT
LEFT
HEEL CONTACT
100 PER CENT
1.2 SECONDS
TIME

Figure 2



ENERGY LEVELS
EXPERIMENT NO. 1 - LOAD 10 KG ON TRUNK
DATE: 12/7/66
SUBJECT: P.KRONER
GRADE: LEVEL
SPEED: 73.2 M/MIN
ENERGY LEVEL, CALORIES
25
20
15
10
5
0
BODY TOTAL
H-A-T TOTAL
H-A-T HORIZONTAL KINETIC
BOTH LEGS TOTAL
LEFT LEG TOTAL
H-A-T POTENTIAL
LEFT THIGH TOTAL
LEFT SHANK TOTAL
LEFT FOOT TOTAL
H-A-T VERTICAL KINETIC
LEFT HEEL CONTACT
RIGHT HEEL CONTACT
LEFT HEEL CONTACT
10 20 30 40 50 60 70 80 90 100 PER CENT
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 SECONDS
TIME